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FRIDAY, MARCH 13, 1896.

A LECTURE UPON ACETYLENE.*

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MSS. intended for publication and books etc., intended for review should be sent to the responsible editor, Prof. J. McKeen Cattell, Garrison-on-Hudson, N. Y.

A YEAR and a-half ago, if a chemist had been told that a new illuminating gas could be obtained from the evil-smelling product with which he was only too well acquainted in the laboratory, namely, the acetylene which forms whenever a Bunsen burner strikes down, he would have said that the idea was absurd. If a physicist had been told that the electric furnace was to be used to produce illuminating gas on a commercial scale he would have said it was quite impossible. But distinguished electricians were explaining that the telephone was impossible, while Graham Bell was inventing that instrument. So that scientific men will be well advised not to utter general opinions about the possibilities of the success of any new enterprise, and I shall endeavor to confine myself to the statement of certain facts and to the description of laboratory experiments, which constitute some new data which can be used to form an opinion regarding at least one side of this subject.

The chemistry of the manufacture of acetylene is very simple. Quicklime is reduced by carbon in an electric furnace to carbide of calcium, and enough carbon is taken not only to combine with the calcium to form carbide of calcium, but also to burn with the oxygen of the quicklime

* Delivered before the Society of Arts at Boston, January 23, 1896.

and to remove it as carbonic oxide. The process is represented by the equation: $\text{CaO} + 3\text{C} = \text{CaC}_2 + \text{CO}$. The carbide is obtained as a melted mass with crystalline structure, which when brought in contact with water is transformed to slacked lime, and to acetylene which is given off as a gas. The formula for this transformation is: $\text{CaC}_2 + 2\text{H}_2\text{O} = \text{Ca}(\text{OH})_2 + \text{C}_2\text{H}_2$. All the alkaline earths and alumina have been subjected to the same treatment, and it has been found that the carbides of barium, strontium and calcium have similar formulæ and give off acetylene when treated with water. The carbide of aluminum has the formula: Al_4C_3 , and evolves marsh gas when treated with water. It may be added that a mixture of silica and carbon yields the carbide of silicon, SiC . The compound is formed when the two boches meet as vapors in the intense heat of the electric furnace and combine as a sublimate of beautiful crystals, now sold under the name of Carborundum. The powdered crystals have sharp cutting edges, hard enough to scratch rubies, and consequently make an excellent polishing and grinding material.

It is to be noticed that this formation of carbides affects the elements which make up by far the larger part of the earth's crust, so that from a geological as well as a chemical point of view these newly discovered transformations are of the utmost importance.

The reduction of these oxides to carbides is only possible at the high temperature of the electric furnace, and it is very interesting to note that at three very different stages of temperature we have such different conditions presiding over the union of the elements that each temperature corresponds to a new chemistry.

The temperature of the electric furnace, which has been estimated to be from $3,500^\circ$ to $4,000^\circ$ Cent., may be considered as intermediate between the sun's temperature,

estimated by different physicists at $5,000^\circ$ to $8,000^\circ$, and the temperatures of our smelting furnaces, which range from $1,200^\circ$ to $1,500^\circ$. Now, in the sun's atmosphere, spectroscopic observations tell us that the elements exist uncombined, and we can even observe great masses of free oxygen in the presence of heated hydrogen and of metals so transformed in the properties which we are accustomed to recognize that they do not combine, but rise as vapors from the hottest part of the sun, condense and fall back in metallic clouds, which we know as sun spots. Here, then, is a temperature which is too hot for chemistry, if we define chemistry as the science of the combination of bodies.

The next temperature on a descending scale that we have access to is that of the electric furnace; here a partial combination only is possible; much of the oxygen remains free; carbon only burns to the non-oxide of carbon, and the carbides and not the oxides of the alkaline earths are the stable forms of combination.

Then, at a lower temperature the bright red heat of our smelting furnaces, the same carbides formed in the electric furnace, when exposed to free oxygen or to air, burn to oxides and to carbonic acid, and at a still lower temperature these two unite to form carbonates represented by the chalk and magnesian limestone which make so large a part of the earth's crust. Nature has so adjusted her processes that a small residue of oxygen remains, which, mixed with nitrogen, constitutes the vital air of our atmosphere. The carbides of aluminum and silicon burn in a similar way with oxygen, and the stable condition at any temperature lower than a bright-red heat is that of silicates and carbonates which make the chief strata of the earth.

The oxidation of carbides, which became possible when our globe cooled down to a red heat and solidified, has perhaps been a

superficial one, and the denser material below the crust may consist of carbides of the alkaline earths and carbides of the heavy metals like iron, and finally the metals themselves.

It is only within the last two years that experiments with the electric furnace have enabled us to study these new transformations at a high temperature, and have given us the means of estimating what must have been the primitive condition of the earth during long geological periods.

Berthelot, Moissan and others have pointed out that the evolution of marsh gas from volcanoes may be an indication of the existence of Plutonic remnants of carbides, dating from a period of higher temperature, and which we now know may give off gas when brought in contact with moisture.

The most important and original experiments made with the electric furnace have been published in the *Comptes Rendus* of the French Academy of Sciences by a young chemist, Henri Moissan, who had already distinguished himself by the discovery of fluorine. One of the first results which this new instrument gave in his hands was the artificial production of diamonds made by dissolving carbon in iron, and he then undertook a complete study of the formation of the carbides of the metals. Moissan's paper which interests us most directly was published on the 5th of March, 1894. It contains a full account of the formation of pure crystallized carbide of calcium and of its reactions with oxygen, sulphur, chlorine, etc., and a complete account of the formation of acetylene by the action of water upon the carbide, and nothing of scientific interest has since been added to the chemistry of acetylene, except some few experiments in European laboratories, notably upon its silver compounds.

French physicists have, however, made some very important measures of the thermic conditions which preside over the for-

mation and decomposition of acetylene. They are a continuation of the admirable study of this singular gas, which was begun by Berthelot in 1859, and we shall find them of great value for explaining the properties which make acetylene useful or dangerous as an illuminant. The lecture will be confined strictly to the statement of facts which bear upon the proposed new gas industry, and no place can be given to the long-known laboratory processes for making acetylene, and to many experiments which display its general properties.

The idea of using this laboratory product upon a commercial scale originated in the United States, and the merit of it is due to Mr. T. L. Willson and Messrs. Dickerson and Suckert, who have secured patents; but it is important to insist upon the fact that they are not the discoverers of the crystalline carbide of calcium, nor of its transformation to acetylene and to hydrate of calcium. Moissan's publication of March 5, 1894, antedates their patents by many months, and describes completely the whole chemistry of the manufacture of acetylene.

No mention is made of Moissan's work in the reports published by the acetylene company in a lecture by Willson and Suckert before the Franklin Institute, and in a lecture before the London Society of Arts by Prof. Lewes. In these reports Mr. Willson is represented as having discovered the mode of formation of calcium carbide in the electric furnace by the reducing action of carbon upon refractory oxides. It is stated that the experiments were begun by Mr. Willson in 1888.

In such matters dates of discovery can only be established by publications, which in this case are to be found in the Patent Office reports. Mr. Willson took out four patents in 1889-1892 for electric smelting processes, and in several of them the use of carbon with refractory oxides is specified. The design seems to have been to make

aluminum and its alloys and perhaps other metals. No mention is made in the reports of carbide of calcium nor of acetylene. Dickerson and Suckert, December 31, 1894, nine months after Moissan's publication, patented a process for evolving and condensing acetylene made from the carbide of calcium. And June 18, 1895, is the date of the first patent by T. L. Willson in which the report specifies the production of carbide of calcium.

Many statements have been published concerning commercial aspects of the new enterprise, but it will suffice to say here that it has not yet reached a stage at which the vital question of the cost to the consumer of the carbide of calcium can be fixed by the quotation of a market price. Small quantities can be purchased for experimental purposes in New York at a price of \$5 per 100 lbs. But the manufacture in the United States does not exceed one ton per diem and is carried on at Spray, in North Carolina, a somewhat inaccessible place, and no complete account of the process has yet appeared in the best-known scientific periodicals. The commercial carbide, unlike that made by Moissan, probably contains compounds of calcium with the ash of coke, but no complete analysis has been published. Some of the statements made about the number of cubic feet of acetylene are obviously inaccurate because the figures 5.89 to 6.35 cu. ft. acetylene per lb. carbide are as high or higher than could be obtained if the carbide contained no ash and were absolutely pure.

The accurate measure of the gas given off by the carbide is not easy and requires the construction of a special apparatus. The writer has examined a number of samples of commercial carbide, and found that 70 to 92 per cent. of the theoretical quantity of acetylene could be obtained from them. It appears that the product which can be made to the best advantage is one which contains

84.6 per cent. of pure carbide, and which gives 5 cu. ft. of gas per pound; or, for a ton of carbide, 10,000 cu. ft. acetylene, two-thirds saturated with moisture, and measured at 60° Fahr. and 30 inches barometer. Summer and winter variations of temperature, together with barometric variations, would cause a difference of more than 15 per cent. in the uncorrected measure of the gas, and gas measured in a mountainous region, without correction for the low barometer, would differ far more from the standard amount.

If the acetylene industry shall succeed, the cost of the carbide will have to be adjusted to the price that the consumer may be willing to pay for gas, and it is preferable to treat the subject from this side and to show, as far as laboratory experiments with materials at hand will permit, what will be the probable value to the consumer of acetylene gas.

A very simple experiment illustrates in a beautiful way the ease with which acetylene can be made from the carbide. Direct a small stream of water on a half-pound lump of carbide, ignite the gas and show that the more water is poured on, the more flame is obtained. Various forms of generators can be used for the gas. The simplest one is a bell glass floating on water and containing a few lumps of carbide in a sieve. As soon as the bell glass descends so that the sieve touches the water, a shower of fine sediment of slaked lime can be seen to separate from the carbide and fall to the bottom of the jar, while the gas generated soon causes the bell to rise and removes the carbide from contact with the water. Thus the apparatus can be made to work automatically, generating gas only as fast as it is used; but it is not fitted for permanent use, because the moisture from the water generates gas, even when the contact has ceased, and the bell gradually rises, so that after twenty-four hours gas would escape if it were not used during the interval.

It is in every way preferable to separate the generator and the gas holder, and such arrangements can easily be made automatic.

The acetylene company has patented a tank for generating the gas under sufficient pressure to liquify itself, and proposes to distribute liquid acetylene in cylinders under a pressure of 600 to 700 pounds to the inch; of this project more is to be said later.

It is certain that a company purchasing the carbide of calcium and using an existing gas plant could generate acetylene and distribute it through mains at a very small expense, and with little skilled labor, so that when a price for the carbide had been established by contract the cost of the gas could be easily estimated; let us see what price such a company could expect to obtain from a consumer.

VALUE OF ACETYLENE AS AN ILLUMINANT.

Suppose we take the case of a competition with the gas companies of a large town. At first sight it would seem fair to say we pay for the light gas gives, and if a new gas gives ten times more light we are willing to pay ten times more, particularly if it possesses any other advantages; our gas bill will remain the same.

Here we come upon ground where the facts can be tested by experiments. I have made a large number of measures of illuminating power and find that with a new burner particularly suited to it 5 cu. ft. of acetylene per hour will give 200 candle power; 5 cu. ft. of Boston gas will give a little more than 25 candle power. The Brookline gas is a little brighter. From this point of view alone then we can pay in Boston about \$8 per 1,000 cu. ft. for acetylene when we pay \$1 per 1,000 cu. ft. common gas. But will the gas bills remain the same at this ratio? More light will probably be used and the householder will be led into a more extravagant consumption, and he must decide what he is willing to pay for

the new luxury. We must count then with the tastes of the consumer, and these can only be translated into money values after long trial of the new light in many houses.

Besides the question of meeting the desire of the consumer for more or less light is another, which must be taken into consideration depending upon his expertness in burning gas and the care he is willing to take in getting economical results.

No. 1. A Sugg-table fishtail burner is shown, burning just 5 cu. ft. per hour and giving the light of 25 candles. If more or less than 5 cu. ft. of gas is passed through it per hour it gives a lower efficiency and the light costs more. The law in Massachusetts, 1882, requires that the candle power should be tested with the most efficient burners, and I have used the best one for water gas. Coal gas would have given more candle power in an Argand burner. Burning gas economically is an art which is only understood by experts, and here again the habits of consumers disturb calculations; they are not usually willing to take the pains to get the best burners, as the following experiment will show.

No. 2 is a gas burner taken off the pipes in the Technology building and represents the average condition of burners in dwellings. About one-half the illuminating power of the gas is lost in this burner, and few people think of having the burners changed when they become inefficient.

If I put a globe over the burner, about half the light is absorbed, so that with a bad burner and with a milk-glass globe we pay about four times as much as need be for light; but the use of a globe is often necessary for comfort. The acetylene gas gives a different colored light, and I thought it might pass through the globe in larger proportion, but on measuring the candle power I found this was not the case. Perhaps a globe can be found that will especially suit acetylene light.

An important question then is to be answered before we can compare the lighting power of gas and acetylene. Is an acetylene light more tolerant of lack of care in the burners and of variations in the pressure than is the case with common gas? The most superficial observation shows that the two gases must be burnt in a very different way.

Gas burnt in an acetylene jet gives less than one-tenth of its true lighting power, and acetylene burnt in a common gas burner gives a yellow, smoky flame, and when turned down to a small flame it deposits soot on the jet, clogging the burner, if the opening consists of a straight slit. Even the very fine fishtail burners with a straight slit intended for oil gas suffer from this defect when the acetylene flame is turned down.

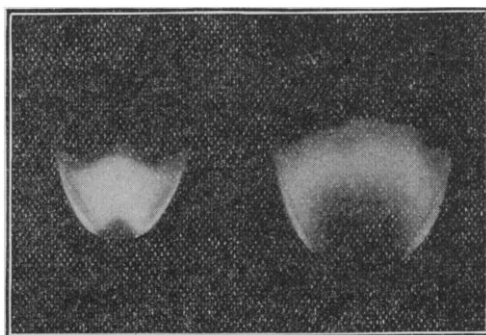
It appears then from the last experiments that the choice of burner and the mode of using it are very important factors in determining the value of any kind of illuminant, and hundreds of pages have been published on this subject with reference to oil and gas light, and it may be added that the results are not yet concordant.

Acetylene can not well be burnt in an Argand burner nor with the devices that succeed with petroleum lamps. A fishtail flame with a good exposure to the air must be used, and the best form of burner is that which throws the swiftest stream of acetylene into the air in the form of a very thin sheet.

A lava-tip burner has long been used for gas in which the opening is not a slit, but two small holes. The construction of these burners can be well shown by passing gas through two blowpipe jets, and when the two long jets of flame are made to impinge on each other at nearly a right angle they spread out into a fishtail form. Acetylene can be burnt in very small lava tip jets of this class, and gives about 30-candle power, but the light can not be turned low without losing its efficiency and smoking.

An experiment can easily be made which shows how large a quantity of air is required to render acetylene flames smokeless. Mix acetylene gas with measured quantities of air up to $1\frac{1}{2}$ volumes of air and burn the mixtures in a slit fishtail burner. It will be found that the acetylene does not diminish notably in illuminating power. Larger proportions of air begin to destroy the brilliancy of the flame. The same trials with common gas show that a very small proportion of air renders the flame less luminous. Suitable burners must be chosen in each case.

Acetylene can even be burnt mixed with one-third its volume of oxygen, giving a very brilliant flame. These experiments are only of practical value in indicating the kind of burner which should be chosen for acetylene. Another quality of the flame is very instructive from the same point of view. The acetylene flame clings to the burner in an extraordinary way, so that it is difficult to blow it out, and the luminous part of the fishtail flame almost touches the jet, while in a gas flame a large blue zone separates the luminous part from the jet. An instantaneous photograph shows well the character of the two flames and also their comparative actinic powers.*



By exploring the flame with a bit of platinum wire, it is easy to see, by the in-

* In the reproduction the gas flame appears relatively too bright.—ED.

tensity with which it glows, which is the hottest part, and also to recognize that the luminous part deposits soot on any cold object.

These experiments led to the idea of constructing a new form of burner for acetylene gas, in which the jets should be very fine and very perfect in form, and which should give the best possible access of air, and which should bring a very small section of metal in contact with the flame in order to avoid smoke and the deposit of soot.



The form eventually chosen is shown by the sketch. The burner is made of brass with nickel or steel tips. The extreme points in contact with the flame may be tipped with platinum or silver, but steel answers the purpose quite well. The most essential feature is that the tips should not be larger than $\frac{1}{16}$ inch in diameter. These burners abstract very little heat from the flame and consequently give more light than the usual form for the same candle power. They do not smoke with any height of flame. They burn acetylene advantageously with the 10- to 20-candle-power light to which we are accustomed. Lava tips are not well suited to such small flames, because the section in contact with the flame is about 20 times larger and abstracts so much heat that the metal setting for several inches in length becomes very hot. Loss of heat occasions loss of light.

It is particularly important in burning acetylene that a large supply of air should be drawn into the flame by the suction of the gas jets which issue from the two orifices of the burner. The steel jets described above provide for this by their perfection of

form, as they are bored from their base and have the same proportions, which have been found to throw the swiftest stream under a given pressure with a hose nozzle.

It seems probable, in view of the careless use of burners in the ordinary consumption of gas, that one quality of acetylene will tell in its favor. With a suitable burner acetylene will tolerate greater variations of pressure than common gas. This point was determined by more than 100 measures of the candle power taken with the two gases burning under different pressures.

The smallness of the acetylene flame required to give off a brilliant light is a point in its favor, allowing the use of a great variety of globes and shades for tempering or reflecting the light.

The same quality will be found of advantage when a strong light is to be concentrated as nearly as possible at the focus of a mirror or of a lens, as in locomotive headlights or in lanterns for projections.

It was hoped that the quantity of light given off by duplex or triplex acetylene flames would show a particularly economical consumption, but the results of measures of the candle power of such flames with or without chimneys were disappointing. It appears that defect of air supply with such flames more than counterbalances the effect of the heat which one flame communicates to the other.

It might be desirable to use the existing gas plants and to deliver, as heretofore, a gas of 20-candle power suitable for heating or lighting. Such a project seemed very easy of fulfilment, since it was at first supposed that acetylene could be used to enrich common gas, and in that case no changes would be required in the mode of distribution nor in the form of burners. Experiments have shown that it can be employed to enrich coal gas, but that water gas, which is so largely used in this country, cannot be enriched by acetylene. Water gas has little

illuminating power and requires to be enriched by passing petroleum oil into the retorts during the manufacture, and it is only when water gas has already been brought up to a certain candle power that acetylene gas can be mixed with it without losing its effectiveness as an illuminant; so that it cannot be used as a substitute for petroleum to enrich crude water gas.

There is no apparent reason *a priori* why an admixture of a combustible gas should deprive acetylene of its illuminating power, and it is interesting to examine separately the effect of each one of the constituents of water gas to see which one has this property.

Brookline gas, besides 16% of illuminants derived from oil, contains equal quantities (about 26%) of hydrogen, marsh gas and carbonic oxide. If each one of these is burnt separately with acetylene it appears immediately that it is the carbonic oxide which renders the acetylene flame non-luminous. Ammonia also has a singular effect upon common gas and upon acetylene, nearly destroying the lighting power and giving a beautiful faint purple flame with curious marked fringes, but ordinarily only traces of ammonia are contained in gas. Nitrogen has much less effect than ammonia or carbonic oxide in destroying the illuminating power of acetylene.

The preceding statements tend to show that a summary of the qualities of acetylene gas, as compared with common gas, must comprise other data beside the measures of candle power, and I have endeavored to point out some of the peculiar properties of the new light which are advantageous. The price and the taste of the consumers must decide the question of competition.

The gas of small towns is usually poorer in quality and higher in price than in large towns, and perhaps the opportunities for the introduction of acetylene are greatest in this direction. Consumers may be willing

to pay \$15 per thousand for acetylene gas where they pay \$1.50 for 16-candle water gas or coal gas.

I should expect to see it first introduced to replace the very expensive oil gas used in railroad carriages, and also for special purposes where great brilliancy and concentration are required, like the head lights of locomotives. For such purposes the Welsbach light cannot be used, because it is destroyed by jarring. The adherence of the flame to the burner is an advantage for railroad use, making the flame hard to blow out. For shop-window illumination the Welsbach light, which is very much cheaper than gas burnt in any other way, seems to be beyond the reach of competition; and the Auer burner, which is similar, is now used for street lighting in Paris, and these incandescent lights work well wherever the light is not shaken, and where the disagreeable green tint is not an objection.

For country houses acetylene light seems well fitted and might replace the very bad illumination of gasolene light.

Much skill and special knowledge are required to run gas works, while the making of acetylene from the carbide or its distribution as a liquid is so simple that acetylene stations could be established in many villages too small to make gas works pay. Moreover the winter consumption of gas is two or three times that of the summer, when the gas plant lies idle in part. With acetylene there is an advantage in this direction, because the value of the plant would be much less.

The whiteness of acetylene light renders it useful for displaying or sorting colors, and some experiments made with Mr. C. R. Walker show that, for photographic purposes, when equal quantities of acetylene light and of water-gas light, measured by candle power, are compared, the acetylene light has two and one-half times the actinic value of the other.

POISONOUS QUALITIES OF GAS AND ACETYLENE.

Continuing the comparison of common gas and acetylene, let us see how the case stands from a sanitary point of view. We see reports in the newspapers of deaths and attacks of illness from gas poisoning, the dropping out during the night of the core of a gas cock or a break in a pipe, would often be an accident fatal for the inmate of a small, close bed chamber. Recently persons have been poisoned by a defect in the gas main outside of their houses. Workmen are frequently made ill by a leak in the gas mains while working in a trench, but the officers of the gas companies state that such accidents are very seldom fatal.

There is no question then about the poisonous qualities of common gas and particularly of water gas. Is the new illuminant likely to be less dangerous?

The poisonous constituent of common gas is carbonic oxide. London gas contains 3.2 to 7% ; Paris gas 7% ; Berlin gas 8% ; Boston gas 26%.

Formerly there was a legal limit of 10%, which is now removed, and the introduction of water gas has raised the percentage to this very high and dangerous amount.

Carbonic oxide is not irritating or corrosive, and it seems strange that a compound so nearly allied to carbonic acid, which is innocuous, should act as a rapid poison.

The mode of action is this: Carbonic oxide is absorbed and retained by the blood in a way quite different from other gases. It combines with the red corpuscles, and the compound shows under the spectroscope special absorption bands, which make the recognition of its presence easy.

Blood which has taken up a certain quantity of carbonic oxide no longer is capable of taking up oxygen in the lungs and conveying it through the circulation, and death by suffocation ensues, just as if there were not enough oxygen to breathe.

The blood is so sensitive to carbonic

oxide that so little as 0.03 % in the air can be shown (Bull. Soc. chem. (6) 663) when a solution of blood is brought thoroughly in contact with a mixture containing carbonic oxide.

The best way to bring a liquid in contact with a large body of air or gas would be to have it circulate by means of minute canals, using a pump to keep the current in motion through the cell walls of a sponge, while the air was continually changed by squeezing and relaxing the sponge. We can find such a little machine in a very perfect form in the body of a small animal, the veins and arteries constituting the canals, the pump being represented by the heart, and the sponge by the lungs.

If we sacrifice a mouse as a martyr to science and enclose him in a tight box containing air with a known percentage of carbonic oxide, and kill him after 3 or 4 hours, we can detect the carbonic oxide absorbed by his blood.

A similar method is best suited to discovering whether acetylene is absorbed by the blood. We might suspect that this would be the case since the two gases have in common the peculiar property of being absorbable by solutions of subchloride of copper.

Grehant (Comptes Rendus 1895, II., 565) made a careful comparison of carbonic oxide and acetylene in respect to their poisonous qualities upon dogs. He took care to have 20% oxygen always in his mixtures, so as to give it the vital quality of air and not to kill his animals by suffocation. He added 1% carbonic oxide (*i. e.*, enough Paris gas (containing 7% CO) to give 1% carbonic oxide). After 3 minutes the animal suffered; after 10 minutes the dog was very sick and his blood contained 27 volumes per 100 of carbonic oxide. The dog would have soon died if the experiment had been prolonged.

In a mixture containing 20% oxygen and

20% acetylene a dog breathed without inconvenience for 35 minutes. His blood contained 10% acetylene, less than $\frac{1}{50}$ the rate of absorption of carbonic oxide and not a larger percentage of acetylene than would have been absorbed by water. The mixture contained much more acetylene than could ever get into the air of a room, and in fact in a dwelling house a much smaller quantity would produce an explosion.

A dog was killed by breathing 40% acetylene and 20% oxygen in 51 minutes; another in about 30 minutes by 80% acetylene and 20% oxygen. A guinea pig was *not* killed in 39 minutes by the same mixture.

L. Brociner (Comptes Rendus 1895, II., 773) had made similar experiments in 1887, and concluded that acetylene was not poisonous. It is not more absorbed by blood than by water. It has *no* specific action on blood. Sulphide of ammonium reduces such blood normally. It has no special absorption band.

Berthelot and Claude Bernard 30 years ago found acetylene not poisonous.

Moissan (Comptes Rendus, 1895, II, 566) says pure acetylene only has an ætheric agreeable odor.

Bistrow and Liebreich in 1868 (Ber. I., 220) pronounced acetylene poisonous, but this opinion is contrary to that of Berthelot and of Claude Bernard, and Berthelot has recently stated anew that pure acetylene is not poisonous, and has pointed out that the old method of preparation of acetylene by means of the acetylides of copper may contaminate the gas with prussic acid (Comptes Rendus, 1895, II., 566). It may be concluded then on the best authority that *pure* acetylene is not poisonous.

The smell of freshly prepared acetylene made with commercial carbide of calcium would lead one to suspect that the gas contained phosphoretted hydrogen and Wellgerodt (Ber. 1895, 2107, 2115) detected its

presence in acetylene by passing the gas through nitrate of silver solution. I also got by another method a good molybdate test for phosphoric acid, before I knew of the above publication.

The phosphorus is probably derived from phosphates in the quicklime and in the ash of the coke used for making the carbide of calcium. Moissan used a pure carbon obtained by charring sugar, and his carbide gave pure acetylene free from disagreeable odor. The previous statements that acetylene is innocuous may only apply to pure acetylene, and it is important then to make a special examination of commercial acetylene to see if it contains dangerous constituents. I have only found one statement on this subject contained in the *Electrical Engineer*, New York, November 13, 1895, p. 469.

Dr. W. H. Birchmore says that 1 cu. ft. of acetylene in 10,000 cu. ft. of air produces headache in twenty minutes, and that so small a quantity of acetylene is not perceptible to smell.

I have frequently breathed air containing enough acetylene to be very plainly noticeable from its smell, and have not suffered the slightest inconvenience. It seems probable that individuals differ greatly in their susceptibility to poisons of the class to which phosphoretted hydrogen belongs. It is also quite possible that other poisonous gases in very small quantity may constitute impurities of acetylene. Dr. Birchmore performed a single experiment upon an animal and states that one part of acetylene in 10,000 parts of air killed a guinea pig in six hours; sickness came on in ten minutes. The blood lost its power of absorbing oxygen, as in a case of poisoning by cyanhydric acid. He did not examine the blood for acetylene. Experiments of this kind should be repeated by competent physiologists, and the blood should be carefully tested. It is quite certain that in this case the death was

caused by some other body present and not by the pure acetylene.

If it is found that phosphoretted hydrogen or some similar impurity is present in dangerous quantity, they can probably be removed by a proper treatment of the gas.

Arsenuretted hydrogen might also be present, but I have failed to find any trace of it in commercial acetylene.

It has been said that acetylene gas could never act as a poison, because an escape from a leaky pipe would attract the attention of a person, even while asleep, by its irritating action upon the throat, producing coughing. The statement is contrary to all my observations.

Further experiments upon this subject are required, but the evidence already accumulated seems to be favorable to acetylene as compared with water gas, and if the new illuminant can be made for a reasonable price and can be quite freed from poisonous impurities it should become a formidable competitor with water gas. On the other side, however, we shall find that the danger from explosion will call for special precautions in the use of acetylene gas.

DANGER IN USE OF LIQUIFIED ACETYLENE.

There will be an evident advantage, if acetylene gas lighting succeeds, to begin by introducing it without putting down mains and setting down generating houses; this can be done by supplying customers with liquified gas. A cylinder holding say 1,000 cu. ft. gas compressed in a space of less than 2 cu. ft. can be attached to the gas pipes of a house in place of a meter.

This new gas service is, however, not so simple as would at first appear. Two cylinders must be used at once, or at least a second one must be brought before the first is exhausted to make the supply continuous, otherwise we should have the disagreeable surprise of finding the gas extinguished. A gauge on the cylinders must

be watched to see when No. 1 must be cut off and No. 2 turned on. Neglect in care of this will cause extinction of the gas and discredit of the system. The gas companies have accustomed us to a constant supply through mains at an even pressure and have set a high standard of convenience.

The cylinders contain gas at a pressure of 6 to 700 lbs. A reducing valve, always kept in order, must reduce this pressure to 1 oz.=2 inches water. The Pintch valve employed on railroad lines is used, but we must ask the question: Will it always keep in order with the care it would get in a private house or tenement house? Then an escape valve is required in case a fault of the Pintch valve throws the whole pressure on the pipes. A mercury seal would answer to empty the gas into the air, and it could be counted on to work satisfactorily, but the gas would be lost each time that the valves got out of order.

All this apparatus makes the use of liquified acetylene somewhat complicated, and in addition to this disadvantage it would present a serious danger in case of fire. The cylinders when strongly heated would be liable to explosion, and it is proposed to guard against this danger by employing a mercury seal to empty them when the pressure exceeds safe limits. This arrangement, even supposing that it always performed its office during a fire, would be open to a serious objection, for if the fire took place in a large building in a town containing, say, 10 cylinders with 5,000 cu. ft. of gas in the 10, this quantity of gas thrown in the air would make an explosive mixture with 20 times its volume of air, or about 100,000 cu. ft. in all, and whether disengaged on the roof or in the street would expose the firemen to a new danger.

If we add to the small annoyances arising from the care of a gas supply which is not constant like that of gas delivered in mains, the danger of explosion of a cylinder

weakened by rust or neglect, the danger in case of fire and the very doubtful economy of the systems, the summary seems unfavorable to use of liquified acetylene, except in places where sufficient space can be had to isolate the cylinders as gasoline tanks are now isolated.

It will be seen later that these cylinders may be exposed to a special danger, although a very improbable one, from the explosive decomposition of acetylene under the impulse of a certain kind of shock.

THE TEMPERATURE OF THE ACETYLENE FLAME.

When we compare acetylene and common gas illumination from the point of view of the products of combustion which vitiate the air of a room, or of the heat which is given off, the conclusions are very favorable to acetylene lighting, because ten times as much common gas has to be burnt to obtain the same amount of light as would be given by a unit measure of acetylene. The heating effect, however, is not in the ratio of ten to one. Ten cu. ft. of Boston gas give 2.42 times as much heat as 1 cu. ft. of acetylene.

Prof. Lewes* has calculated the amount of carbonic acid given off by different illuminants, and finds, for an equal amount of light, that coal gas gives off six times as much as acetylene, and he estimates that the heat from acetylene would not be much greater than from the ordinary incandescent lamp.

The true relations are for the same amount of light: Heat from incandescent light, 1; acetylene, 3; water gas, 9.

Prof. Lewes says, in the same connection: "The flame of acetylene, in spite of its illuminating value, is a distinctly cool flame, and in experiments which I have made by means of the Lechatelier thermo-couple, the highest temperature in any part of the flame is a trace under 1,000° Cent. While coal

gas, burning in the same way in a flat-flame burner, the temperature rises as high as 1,360 Cent."

It is not an advantage, but a disadvantage, that the fishtail acetylene flame should be cool. Its temperature is lowered by the excessive contact with air required for complete combustion, and, if the flame could be made hotter, more light could be obtained for the same quantity of heat. It is scarcely necessary to add that the temperature of a flame has nothing to do with the heat of combustion. Phosphorus or sodium can be burnt at the ordinary temperature, or at a red heat, and the heat of combustion is the same at either temperature, provided the products of combustion are the same.

Lechatelier,* one of the best authorities upon such a subject, does not appear to have measured the temperature of the acetylene flame with his pyrometer, and, in fact, such measurements are very difficult; but he has calculated that acetylene, burned with air, may reach a temperature of 2100° to 2400° Centigrade, and, burned with oxygen, 4000°.

It is easy to melt platinum in a common air blowpipe flame fed with acetylene, but the platinum appears to first form a carbide.

Acetylene, notwithstanding its high cost, may find a restricted use in the laboratory in air or oxygen blast furnaces; it will undoubtedly give a higher temperature than gas or hydrogen.

The preceding description has continually held in view the utilitarian side of the question, and it has been thought simpler to enumerate the items in favor of the economical use of acetylene as compared with gas and not to extend the comparison to other forms of illumination, but the following table mostly taken from the most recent book† on the subject gives the means of

* Comptes Rendus, December 30, 1895.

† Julius Swoboda: Petroleum Industrie. Tübingen, 1895.

* A paper read before the Society of Arts, London.

comparing other modes of lighting. It is to be remarked that authorities differ widely in their estimates, and the cost of gas and electric lighting varies greatly with the locality. Electricity is particularly advantageous when it can be put to other uses during a part of the day.

100 CANDLE LIGHT DURING 1 HOUR.

	Quantity.	Cost. Cents.	Heat of combus- tion, Kilograms of water 1 degree.
Arc light.	0.09—0.25E	1—2.5	57—158c
Incandescent lamp.	0.46—0.85E	3—5	290—536c
Boston gas, \$1 per 1000.	20 cu. ft.	2.0	3380c
Acetylene, \$10 per 1000.	2½ to 3 cu. ft.	2.5—3	1000—1200c
Petroleum lamp.	0.62 lb.—1.0 lb.	2.0	3360c
Carcel oil lamp.	0. 9 lb.	8.0	4200c
Paraffine candle.	1. 7 lb.	28.0	9200c
Spermaceti candle.	1. 7 lb.	54.0	7960c
Wax candle.	1. 7 lb.	61.0	8940c
Stearine candle.	2. 0 lb.	33.0	9700c
Tallow candle.	2. 2 lb.	32.0	

THE CHEMICAL PROPERTIES OF ACETYLENE.

A series of very simple experiments will illustrate the most important properties of acetylene.

To compare its density and its explosive force with those of common gas take two lamp chimneys closed at the top and bottom with corks, and each fitted with an inlet tube at the bottom and with a large brass tube at the top. Fill one with gas and the other with acetylene and light both gases at the upper tube; then remove the rubber tubes from the inlet tubes. The flames will continue to burn at the upper orifice, because each gas rises, floating on a layer of air, which rushes in from below, and the relative densities of the gases may be estimated from the rapidity with which each flows out. The common gas flows out more rapidly and burns with a higher flame than the acetylene, because it is lighter: (density of Boston gas=0.607; density of acetylene=0.91). At the last the flame strikes down into the small residue of each gas, which has become mixed with air in the lamp chimneys, and a slight explosion takes

place, which is notably stronger with acetylene than with gas. The greater density of acetylene explains partly why it should have more illuminating power than common gas, since a cubic foot contains more material. As our object is only to examine the properties of acetylene which have a bearing upon its illuminating power, one test of its chemical activity will suffice. Set free a small quantity of hypochlorous acid gas in a tall glass jar and plunge into it a tube from which a stream of acetylene is issuing, this latter will immediately take fire from the great heat evolved by its chemical action upon the hypochlorous acid. If common gas, or almost any other gas, were subjected to the same test no flame would result.

Acetylene forms peculiar salts with copper, silver and mercury; and these when dry decompose explosively when subjected to a shock or to the action of heat. The silver compound can even be exploded under water and is more dangerous than fulminate of silver.

EXPLOSIVENESS OF ACETYLENE.

What we have learned concerning the extreme chemical activity of acetylene leads us to expect that it would form more readily than other gases an explosive mixture with air, and this proves to be the case.

Experiments using a piece of two-inch gas pipe as a cannon show that 5–6% of acetylene mixed with air forms an explosive mixture; 10–12% of water gas is required to explode with air.

The heat abstracted by the walls of the iron tube prevents the mixture from obtaining its limit of explosiveness, and a still smaller percentage of either gas mixed with the air of a room would explode. Lechatelier (*Comptes Rendus*, 1895, II., 1145) gives 2.8% of acetylene mixed with air as the explosive limit, and it is to be noticed that in a dwelling house the danger from

explosion is enhanced by the inequality of such mixtures. A flame spreading from a spot rich in gas would propagate itself explosively through a mixture very poor in gas.

The danger is enhanced in the case of acetylene by the low temperature at which it takes fire, 480° Cent. Most other gases must be treated to about 600° to take fire and marsh gas, the fire damp of mines, fortunately requires a much higher temperature to ignite, so that a spark from flint and steel does not suffice to cause an explosion. Acetylene burns with greatest increase of volume when the products are carbonic oxide and hydrogen. The violence of combination of acetylene with oxygen can be well shown by igniting equal volumes of the two gases. A quantity equal to 3-4 grains makes a far louder report than the same weight of powder or of nitro-glycerine.

The dangerous properties shown by acetylene need not condemn it, but particular care must be taken to prevent leakage if acetylene gas comes into use; fortunately small pipes can be used and the gas contains no ammonia, which, in common gas, destroys the grease on the stopcocks and promotes leakage.

If instead of igniting a mixture of air and acetylene, the latter alone is passed through a glass tube heated to dull redness, at first a slight change takes place, and liquid benzene and other products condense in the colder parts of the tube; at a little higher temperature the change goes further—carbon is deposited and hydrogen is set free. If the interior of the tube is carefully watched it will be seen that the decomposition takes place with a dull red flame, as if the acetylene were burning with an insufficient supply of air. No air, however, is in the tube; there is no combustion in the ordinary use of the word, and yet we have in the flame evidence of a sudden disengagement of heat. Here we approach the solu-

tion of the problem, regarding the extraordinary chemical activity of acetylene. Acetylene has a supply of heat stored up, which it gives off, whenever it is decomposed spontaneously, burnt in air, or excited by any radical chemical change. The sudden evolution of heat manifests itself as light, quickens combustion and promotes all chemical action.

The exact quantity of heat absorbed and stored up by acetylene, when it is formed by the union of carbon and hydrogen, can be best measured by two experiments. Firstly, burn exactly one cubic foot of acetylene in a calorimetric apparatus, which is merely a device for heating a given weight of water without loss of heat, and find that nearly nine pounds of water can be heated from its freezing to its boiling point. Or, if we take the thermal unit in more general use we find that 407 kilograms of water gain one degree Centigrade in temperature from the heat given off by burning one cubic foot of acetylene gas, measured at 0° Cent. and 76 cm. barometer.

Secondly, take exactly the weights of carbon and hydrogen which correspond to the weight of one cubic foot of acetylene and burn them in the same way under a weighed quantity of water. We shall find that according as we take pure amorphous carbon or diamonds we get a somewhat different quantity of heat. With amorphous carbon and hydrogen 336.5 kilograms of water are raised 1 degree Cent. in temperature. The difference of heating power then between acetylene gas and the same weight of carbon and hydrogen is 71 heat units. The surplus energy stored up in the acetylene and set free when it is burnt becomes evident and is measured, when we find that the acetylene arrangement or combination of carbon and hydrogen atoms is capable of making the elements do more work, that is to heat 71 kilograms more water than when

the same elements are free in the state of amorphous carbon and of hydrogen gas.

When the carbon from carbide of calcium and hydrogen from water combine to make acetylene heat is utilized in changing the carbon from the solid and the hydrogen from the liquid form to the form of a gas. Heat is absorbed in this process which imparts a new energy of motion to the atoms, in the same way that heating water separates the particles to two thousand times wider distances from each other and gives them the energy of motion which is apparent in steam. In this case we can measure the amount of heat required for this work and which is absorbed while it takes place. Unfortunately we can not get similar measures with carbon vapor and solid carbon, and we can only measure a total absorption of heat during the generation of acetylene, and we suppose that the total, 71 heat units, may be made up by the absorption of a larger amount of heat in order to change amorphous carbon to the gaseous state, from which must be deducted the heat which is given out when two carbon and two hydrogen atoms combine to make C_2H_2 . Benzene which has exactly the same percentage of carbon and hydrogen, but combined into quite a different chemical group shows that more energy has been expended in bringing about its chemical arrangement. The signs which attest this are greater stability, smaller chemical activity, and above all the fact that when benzene is burnt it gives off much less heat than the same weight of acetylene does, and in fact only 4 heat units more than the same weight of carbon and of hydrogen.

It has seemed necessary to explain fully how quantities of energy, which can usually be measured in terms of heat, preside over the making of different chemical compounds, and how the dormant heat can be made active again when the compounds are excited to chemical change, and how each one is

stamped as with a birth mark by its special heat value.

This peculiar stamp set upon acetylene is at the same time a token of valuable and also of dangerous qualities. Heat is added to the heat of combustion and brings about more sudden changes and places acetylene with the class of bodies known as fulminates. These are distinguished from explosives like gunpowder by their capability of suddenly evolving stored-up heat, which causes a great expansion of gaseous products. Berthelot has calculated that fulminate of silver develops a pressure of 600,000 lbs to the square inch in the incredibly short time of one-thirty-millionth of a second. The acetylde of silver has similar properties, and the lightest shock suffices to explode it. It occurred to Berthelot to see whether acetylene gas might not decompose spontaneously into carbon and hydrogen with explosive suddenness. We have seen that it decomposes into these products, *but without explosion*, when strongly heated, and only in one way could it be made to decompose explosively. Berthelot succeeded in detonating pure acetylene by subjecting it to the shock of fulminate of silver.

The danger seems very slight that acetylde of copper or some other metal may form in an acetylene gas-holder, and when exploded by friction or heat cause the whole mass of gas or liquid acetylene to explode. The subject, however, is worthy of further study.

As was said in the beginning, the problems which are suggested by this new industry touch on all sides upon some of the most important of the recent discoveries in chemistry and physics, and the ease with which acetylene can be obtained opens the door to many new experiments. Such questions, for instance, as the use of acetylene in gas engines, under special conditions, where the high price would not be prohibitive, would offer a very interesting study. It

does not seem impossible that a gas so active and so easily stored might be exploded with air in a pneumatic gun to give an additional impulse to the projectile.

The laboratory experiments which have been described may perhaps serve as a guide in some directions to manufacturers, but they cannot settle the commercial details upon which the success of the new enterprise depends. Much further study and tests upon a larger scale, with the improvements suggested by prolonged trial, can alone decide whether the new illuminant is destined to supplant older industries built up slowly and surely by the persistent efforts of hard-working and skillful men.

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NOTES ON THE CERRILLOS COAL FIELD.*

DURING August, 1895, the writer revisited the Placer, or Cerrillos, coal field of New Mexico, which is about 25 miles south from Santa Fé. The field is small, apparently a detached portion of the Laramie area extending far southward within the Rio Grande region.

The district of especial interest is a strip lying south from Cerrillos and Waldo, stations on the Santa Fé railroad. It is less than two miles wide and reaches southward to a little more than five miles from the railroad; but evidently all of the workable coal beds are shown, and the transition from bituminous to anthracite is exhibited very satisfactorily. The mines are on Coal cañon, which extends from the Placer, or Ortiz mountains, at the south, to Waldo, at the north, somewhat more than six miles.

The Ortiz mountains are largely trachytic; from them there extend northward two plates, each one about 200 feet thick, which lie between Laramie beds and follow their dip very closely. The upper plate covers

the area east from Coal cañon and is now the surface rock, the overlying beds having been removed. It extends northward to somewhat less than two miles south of Waldo, terminating abruptly at the lower end of Madrid, where are the offices of the Cerrillos Coal Company. The lower plate, about 400 feet below the upper, does not come to the surface on Coal cañon, but it was pierced in a boring on the mesa immediately west and it crops in an arroyo within a few rods further west. Several dikes extend upwards from this plate, one, very large, seen west from Coal cañon, which must have been connected with the upper plate, as it rises very high above the mesa; a second, seen in Coal cañon, not more than 10 or 12 feet wide does not reach the upper plate; a third, very narrow, found in the same cañon at a mile and a half above Madrid, passes distinctly into the upper plate. Prof. Kemp examined the specimens from several exposures and recognized the close relation in composition throughout.

The stratified rocks within this strip belong to the Laramie and the exposed section is somewhat more than 1,000 feet thick. They resemble those of the same age in the Trinidad coal field, but shale is present in greater proportion. Limestone is apparently wholly absent and the sandstones are unusually non-fossiliferous. The coal beds are numerous, but most of them are very thin and several are not persistent in all of the sections.

The only coal beds of interest here are those in the interval between the trachyte plates; they are

White Ash coal bed.....	2'6'' to 7'
Interval	70'
Coking coal bed.....	1' to 2'6''
Interval	80'
Cook-White coal bed.....	3'
Interval about.....	150'
Waldo coal bed.....	4'

*Abstract of paper read before N. Y. Academy of Sciences, January 20, 1896.